THE PHENOMENON OF GLASS MELT RUNNING OVER THE QUELL-PUNKT IN GLASS-MELTING FURNACES

N. A. Pankova[1]

The results of studying the insufficiently researched phenomenon of migration of the surface glass-melt flow known as run-over are reviewed. The physical aspects of this phenomenon and the possibilities of various methods, which contribute to thorough investigation of this phenomenon, are analyzed. The drawbacks of particular experiments are specified.

In periods of imperfect performance of glass-melting furnaces when defects arise (brittleness of finished product, breaking of glass ribbons, nonuniform thickness, occasional bubbles and fine seeds) one should pay close attention to the phenomenon of glass melt flowing over the quell-punkt (run-over).

However, this phenomenon has not been specifically investigated and is not mentioned in manuals on glass technology. Data on glass melt run-over are contained in various papers, mainly in domestic professional journals, however, this issue is never the chief subject of studies. Accordingly, information is scattered and needs to be systematized in a review, since frequently an incorrect use of this term is observed, which leads to conclusion that are not substantiated.

The first mention of glass melt run-over in the Russian literature relates to 1930-s when M. S. Stepanenko (a reputed researcher in thermal engineering) analyzed in his book the studies of German researchers who investigated convective motion of glass melt in glass-melting furnaces using glycerin models).

Results of experimental observations of glass melt run-over have been described in papers on modeling glass-melting furnaces [1 – 6] and also in papers analyzing the motion of glass melt containing various indicators along the furnace [6, 9 – 12]. The scheme of motion of convective glass melt flows at the quell-punkt is indicated in Fig. 1.

Run-over of glass melt is sometimes registered in direct observations of the motion of chamotte floats migrating on the melt surface along the furnace length [12 – 16]. The same phenomenon is described in studying chemical homogeneity of glass melt and its variations in time along the length and the depth of the tank, across the width and thickness of glass ribbons [13, 17, 18].

Thus, this phenomenon has been observed by numerous researchers. Let us consider the main results of above observations (Table 1).

Run-over constitutes migration of a thin surface layer of glass melt. Its thickness is unknown but probably amounts to a few millimeters and is different for different furnaces and different operation schedules. Most researchers believe that this flow originates at the quell-punks (the "flow source" [1, 2]). A complete coincidence of the quell-punkt position and the maximum temperature zone in cross-sections along the longitudinal axis of the melting tank is a rare fact. The length of this zone toward the end of the melting tank is not known either. Some scientists believe that motion of batch heaps along the melting tank at an increased velocity is related to glass melt run-over. In this case one would have to admit that the thickness (depth) of the run-over flow is at least $100 – 150$ mm (the maximum depth of immersion of masses of five-component aluminomagnesium glass batch in a flame-heated furnace). However, nobody has reported a flow of such thickness.

A qualitative representation of glass melt migration at the quell-punkt, i.e., in the spot where a run-over flow can be observed on models [3, 5, 19] is shown in Fig. 2.

In additional to model observations, some nuances of this motion are described in [1 – 4, 8, 11, 15, 18, 19]. The results of these studies carried out in real furnaces can be regarded as an experimental proof of existence of the run-over process.

At the same time, the papers listed above can be classified according to methods used, and their methodic limitations can be specified.

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[1] D. I. Mendeleev Russian Chemical Engineering University, Moscow, Russia.

Observations described in papers	**Methodic limitations or drawbacks of observations**
Direct measurements of velocities of glass melt flows directed toward the cooling area in the maximum temperature zone part by means of floats	Migration of floats is difficult to observe on the melt surface in the maximum temperature zone. Poor visibility of floats moving in the end areas of melting froth
Measurement of depth of surface glass-melt flow	There is no measurement method developed for the heated part of the furnace
Construction of a velocity variation profile for glass melt across its depth near the quell-punkt	The central part along the longitudinal axis is inaccessible to measurements
Measurement of velocities of surface glass melt flows along the melting tank using indicators with registration of zero velocity at the quell-punkt zone	The method for experimental data processing is widely published, however, the part of the furnace along the central longitudinal axis remains inaccessible to taking samples of glass containing indicators

The qualitative representation of glass melt run-over shown in Fig. 1. requires explaining. The authors of these studies on models preferred to indicate the flow motion scheme only at the quell-punkt. The extent of the flows in the longitudinal section of the melting tank is about 3 m (converting the linear sizes of the model to a real furnace according to the most common modeling scales 1 : 35 and 1 : 50).
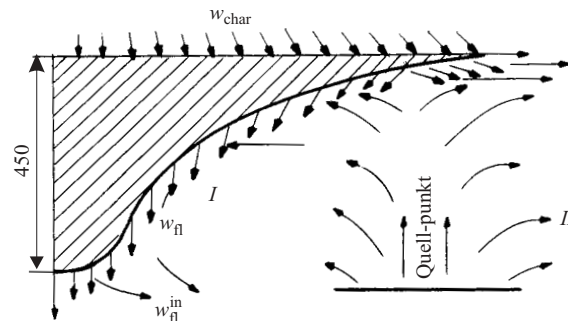

Fig. 1. Scheme of convective glass melt flows at the quell-punkt (longitudinal section of the melting tank along the melt depth): w_{char}) the velocity of batch heaps charged and melting foam entrained by them (surface layer); w_{fl}^{in} is the descending motion of glass melt flows in the inner layers of melt near the end wall of the charging pocket; w_{fl}) is the velocity of clarified glass melt arriving into the working flow; short arrows indicate the direction of newly melted clarified glass arriving to the melt surface in the melting tank and the direction of its entrainment by the descending working flow; long arrows indicate the direction of convection flows in the main convection cycles (longitudinal section of the melting tank); horizontal arrows indicate the run-over flows; I) charging cycle; II) working cycle.

As there are no additional explanations in the papers, it can be assumed that surface run-over was not observed neither before, not after the quell-punkt. This is corroborated by limited capabilities of the physical modeling method when studying the specifics of glass melt motion in surface layers

TABLE 1

| Method of experiment	Conclusion deduced in experiment	Evidence of run-over presence	Limitations of experiment	Published source
Comparing chemical homogeneity of glass melt samples in depth and on the surface of the quell-punkt zone	Surface glass melt layers have poorer chemical homogeneity than in-depth layers	Run-over entrains heterogeneous melt containing inclusions or glass films over the quell-punkt	Samplers are unable to register the thickness of the surface melt samples	[3, 19]
Determination of density of glass melt samples taken from different zones of the melting tank	The melting tank is filled with glass melt of nonuniform density, consequently, of a heterogeneous chemical composition	Surface glass melt layer rich in silica has a minimum density. This layer entrains freshly melted glass melt over the quell-punkt from the batch heaps zone	A thin run-over surface layer cannot be isolated using standard samplers (spoons)	[9, 18]
Studying chemical homogeneity along the melting tank using surface samplers (spoons)	Chemical homogeneity of glass melt improves approaching the maximum temperature zone. Its subsequent variations along the furnace length are insignificant	No negative effect of run-over is registered	Surface samplers (spoon) scoop the melt to a depth of 50 mm from the surface. There is no clear distinction between the run-over flow and the bulk of melted glass	[20]
Studying unmelted parts in surface glass samples taken with surface samplers along the furnace	Complete melting of glass ends before the maximum temperature zone	No entrainment of poorly melted particles into the zone after the quell-punkt was registered in sheet glass furnaces	Limited capabilities of samplers (spoons)	[10, 21]
Studying regularities of variations of bubbles in surface samples along the length of sheet-glass-melting furnaces	Complete clarification of glass melt ends before the maximum temperature zone	No entrainment of bubbles into the zone after the quell-punkt was registered	The same	[22]
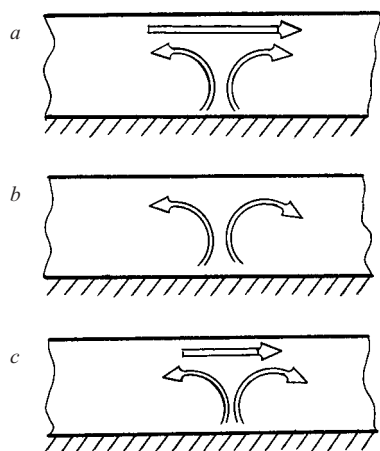
Fig. 2. Expected schemes and velocity of surface horizontal flows at the quell-punkt under different intensity of run-over process: *a*) registered experimental running over toward the working part of the furnace, a high flow velocity; b) total absence of run-over flow; *c*) existence of a medium-intensity run-over flow, a medium or low flow velocity.

and is caused by satisfying the equality of similarity criteria. When the requirements of the similarity theory for Re, Gr, and Pr numbers [1, 2] are satisfies, the equality of number We taking into account the effect of surface tension for the glycerin model does not hold, and no other liquids have been proposed for modeling glass-melting furnaces. Therefore, modeling gives only a schematic representation of the flows. The physical modeling method so far has not given any information on run-over flows before the quell-punk or on open mirror surface of the glass melt.

As the capabilities of this method are limited, one should involve various experimental data on glass melting in tank furnaces to understand the phenomenon of run-over.

K. K. Vilnis [3, 19] reports that chemical homogeneity of glass samples taken from a depth of 400 – 500 mm from the charging pocket using in-depth samplers is significantly higher than the homogeneity of surface glass samples taken from the quell-punkt or from the maximum temperature zone. The author believes that this is caused by surface run-over flows entraining poorly homogenized glass from the end parts of the melting foam, which usually is near the quell-punkt, to the quell-punkt and the maximum temperature zone. This study has given origin and foundation for summarizing and generalizing data, which makes it possible to interpret the chemical composition of the surface layers of the melt or their homogeneity as an experimental proof of the run-over phenomenon.

There are two more methods for studying the motion of glass melt in the glass-melting furnace: the float method and the tagged melt method. In the first case migration of a chamotte float on the surface of glass melt is observed visually. Due to a difference between the density of the float and the melt, the float is immersed in melt to a depth not more

than 10 – 15 mm. However, it should be noted that visual observation through peepholes (technological openings) in the maximum temperature zone is difficult to implement due to a high temperature on the site of the observer's location and due to poor visibility at the end parts of melting foam, although ample statistical data on this subject were published in the domestic literature in 1950 – 1970-s and are quite valuable [3, 4, 6 – 8, 11, 14, 16, 19, 23]. However, there is another methodic limitations: in most cases it was possible to introduce floats and place them on the melt not further than 3 m from the inner surface of the refractory brickwork. V. V. Fokin in 1980-s developed a more successful method for introducing floats into the cooling tank, however, it has not been applied to the melting tank.

Another method for studying conditions and velocities of glass flows in a melting furnace implies observation of glass melt migration labeled by luminescent indicators. This method is widespread. It is used for solving various problems. There are two variants of this method. The first one involves introduction of glass containing an indicator tag into a furnace zone investigated, for instance into the working channel or the cooling zone [7], however glass melt flows in a melting tank have not been studied using this method. Another variant is introduction of indicators through the batch via a charging pocket, i.e., all glass melted since the indicator has penetrated the furnace, is tagged [10, 11, 15, 17, 18, 23 – 25]. The fullest data in this case can be obtained when observation continues until the indicator completely leaves the furnace (the concentration of the indicator in glass samples at the furnace outlet is equal to zero).

A fast variant of the same method is determination of the velocity of the first portions of the indicator moving along the furnace. However, one should bear in mind that not only thin layer of run-over glass melt is tagged, but any glass melt taken in surface samples since the moment the first portion of the indicator arrives into the furnace. It is demonstrated in the works mentioned that a thin surface layer with a tag is clearly registered. The use of this technique makes it possible to obtain data on run-over in a functioning glass-melting furnace, however this particular problem has not been set yet, although numerous data gave been obtained as a by-product of this method.

We should primarily underline a study of V. D. Soskova [12, 13], who used a simple but the most perfect sampler (an upturned water-cooled pan) making it possible to sample a thin surface layer of glass melt tagged with the indicator at the quell-punkt zone. A luminescent photo of glass melt tagged with polarite published in [13] provides a full and objective evidence of run-over in a seven-burner furnace for sheet glass (output 200 ton/day).

In addition, one can specify directions of future research of glass melt flows at the quell-punkt, in order to receive more complete data on this phenomenon.

According to the flow motion scheme (Figs. 1 and 2), it is currently known that in the case of glass melt running over

the quell-punkt there is a thin horizontal layer of glass melt moving over the melt surface. The ascending flows of two main convection cycles diverging horizontally at the quell-punkt after rising to the surface toward the charging end and the working part of the tank seem to be overlapped by a run-over flow of a small, although unknown thickness. To determine its thickness, it is necessary to have a sampler that does not disturb the natural distribution of glass melt layers in the tank and is intended for sampling depth about 100 mm from the melt surface. The natural distribution of the melt should be preserved inside the sampler. Otherwise incorrect results will be registered.

In general the following factors constitute disadvantages of the two methods for identifying the motion of a glass melt:

– in using chamotte floats, a float may become immersed to a depth exceeding the thickness of the run-over flow and, accordingly, its velocity can be affected by the working cycle flow;

– in using the indicator method, tagged glass melt may not only from the run-over flow, but also from deeper layers circulating in the working cycle, may penetrate into the sampler, which leads to some distortion of a concentration of the indicator in samples, however, this does not prevent accurate registering of the time of motion of tagged glass melt.

Of the two experimental methods, the second one can provide a more accurate determination of the type of run-over motion in the sections of the melting tank considered.

Thus, the present review analyses possibilities of various methods for studying run-over. This knowledge is needed both by scientists and by production engineers.

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